

Computer Modeling Laboratory 11

Radiation budget: diurnal and annual cycles

TASK 1

Single-column radiative transfer model was used to calculate the daily cycle of various solar and IR radiative fluxes for clear sky and cloudy conditions. Model runs are provided below. Surface albedo is zero and atmospheric characteristics (e.g., temperature and water vapor profiles) are fixed.

- 1) For the clear sky case, calculate and plot the diurnal cycle of TOA net radiation. Explain your results. Calculate diurnal mean net radiation? Is the atmosphere in radiative equilibrium?*
- 2) Repeat the above analysis for cloudy conditions. Discuss the differences between clear and cloudy cases.*

Radiative transfer model outputs for

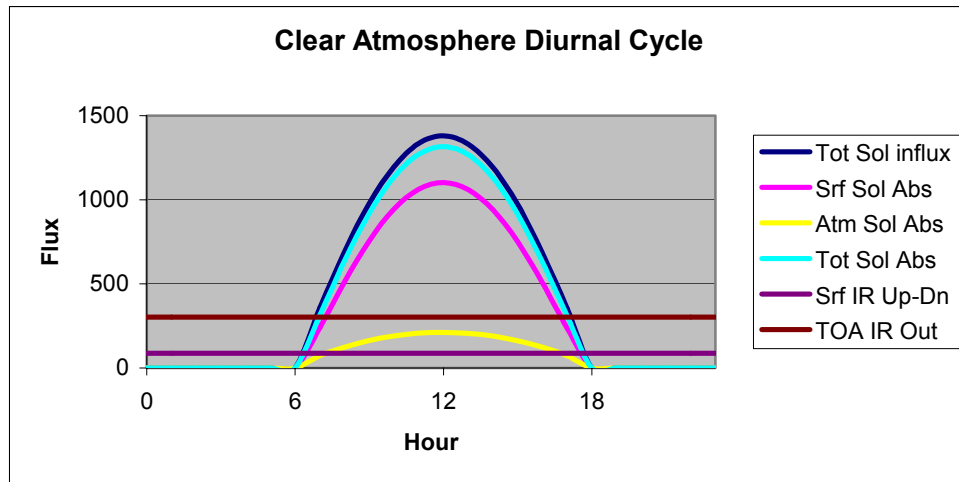
[Cloud](#)

[No Cloud](#)

Answers for Task 1

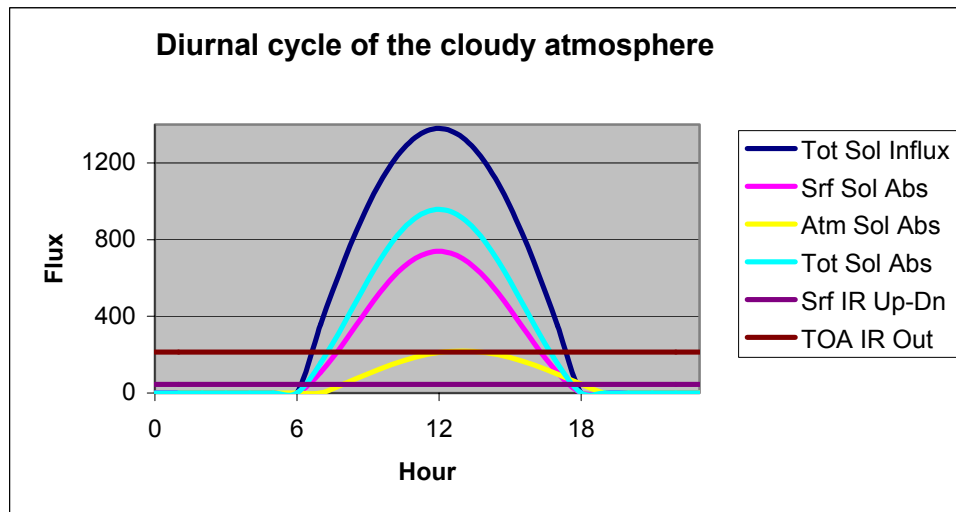
- 1) Clear and cloudy atmosphere TOA net fluxes (Lecture 24). Net flux at the top of atmosphere is the difference between absorbed solar flux within earth-atmosphere system ($F_0(1 - \bar{r})$) and outgoing longwave radiation F_{ir} :

$$F_{TOA}^{net} = F_o (1 - \bar{r}) - F_{IR}$$



At night we have no solar radiation, only IR outgoing radiation. Thus, we have cooling of the system. During the day, solar insolation varies, and net flux has diurnal cycle. Therefore, we have warming.

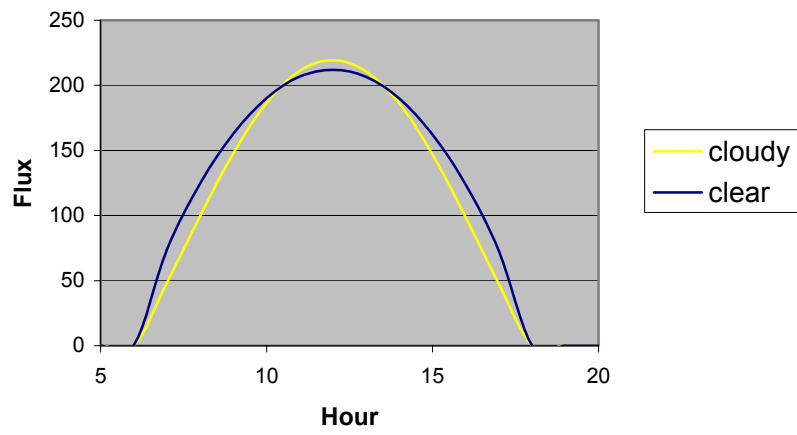
2) Cloudy atmosphere TOA net flux.



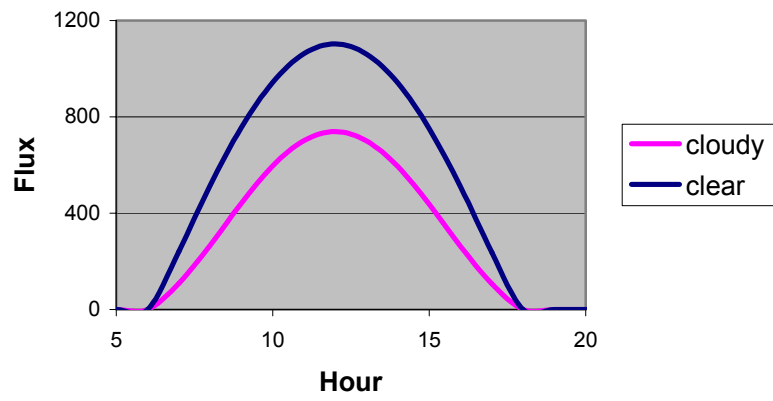
The net flux at the TOA depends on Solar radiation absorbed in the earth-atmosphere system and Total IR radiation outgoing at the TOA (earth and atmosphere). The clouds affect the solar flux:

- Reduce solar radiation absorbed by surface (scatter solar light and reduce its amount that can reach the surface)
- Reduce/increase solar light absorbed by atmosphere (increased scattering that depends on SZA)

Atmosphere solar absorbed

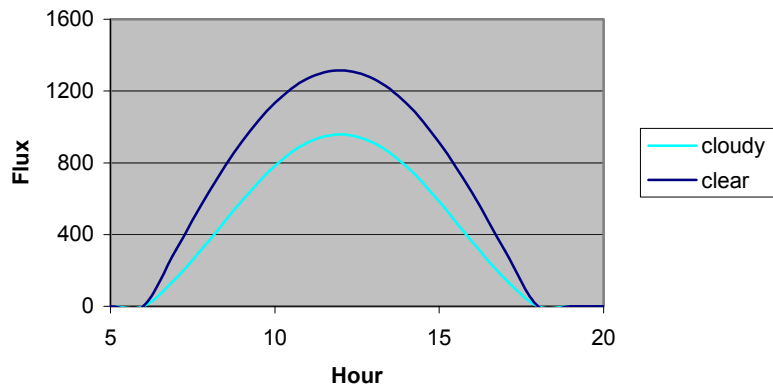


Surface Solar Absorbed



Co

Total Solar Absorbed

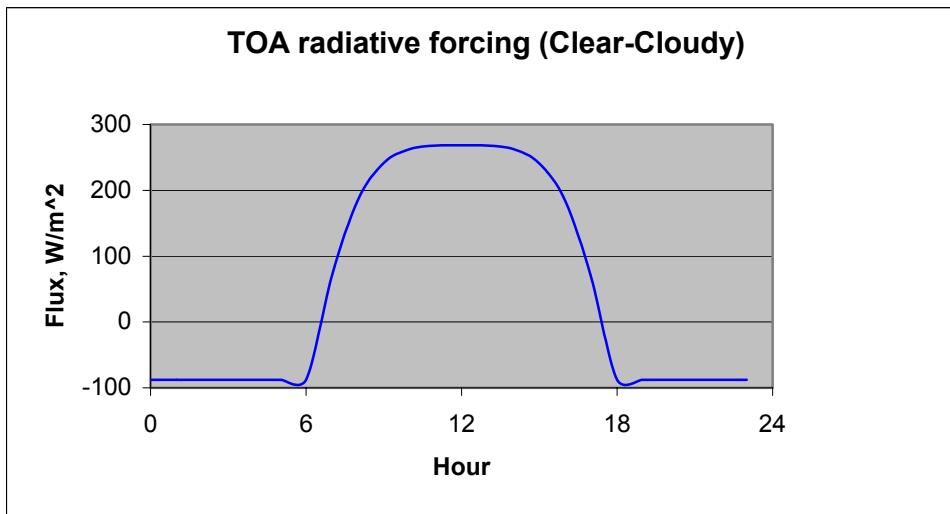
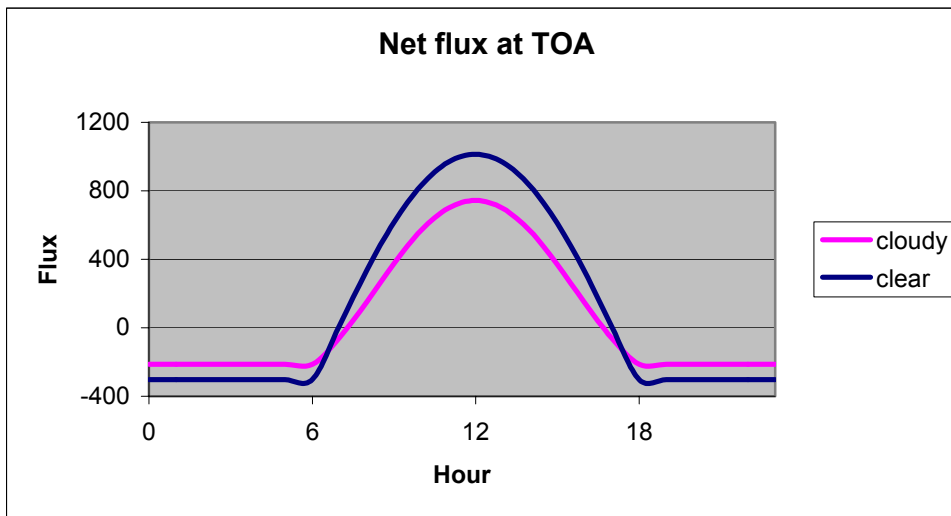


Clouds also affect the IR radiation

- a) Reduce the net IR (up-down) flux at the surface (87 to 45 W m^{-2}) by absorbing radiation emitted by the Earth, and re-emitting the radiation at low temperatures.
- b) Reduce outgoing IR at the top of atmosphere (302 to 214 W m^{-2}).

Therefore, at night (when we do not have solar insolation) clouds reduce net cooling of the earth-atmosphere system.

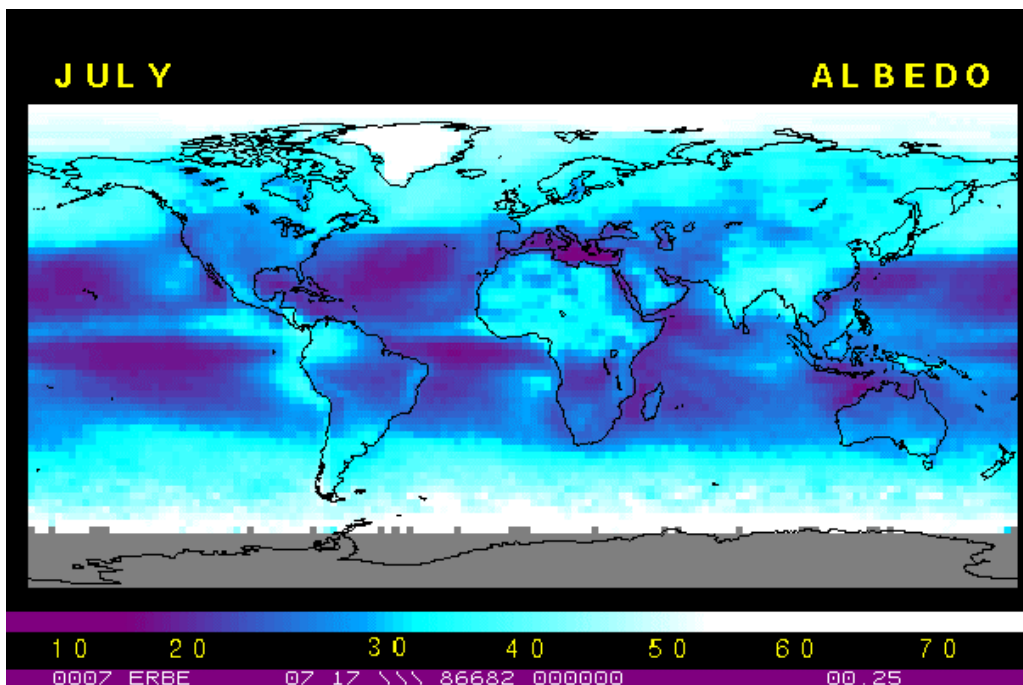
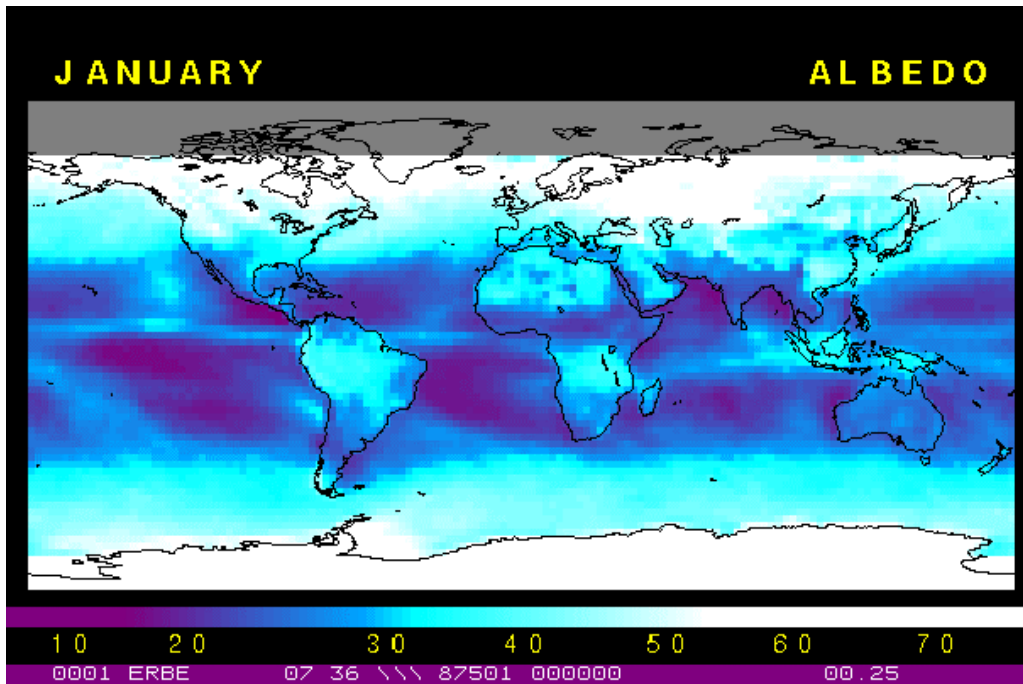
Clouds affect the net solar and IR radiation budget at the TOA.



TASK 2

Earth Radiation Budget Experiment (ERBE) is a NASA sponsored research program to measure global Earth's radiation budget using a series of satellites. Data on the regional monthly mean planetary albedo, outgoing longwave radiation, and net radiation are available at the [Suomi Virtual Museum](#).

1) Briefly characterize the annual cycle of the albedo. Compare the seasonal albedo variations in the tropical regions and in the Polar Regions.



The following is the text from *Suomi Virtual Museum* web page:
<http://profhorn.meteor.wisc.edu/wxwise/museum/a2main.html>

“An object will warm or cool depending on its energy imbalances. If the object receives more energy than it losses, the object will warm. Conversely, if the object losses more energy than it receives it will cool. And if the energy gains equal the energy losses, there is no temperature change. Methods of transferring energy in the atmosphere include conduction, convection, latent heating, advection, and radiation. The method of transferring energy through radiative processes is different from the other mechanisms in that the transfer process does not require molecules.”

“If we consider the planet as a whole, the Earth exchanges energy with its environment (the solar system) via radiation. The radiation balance of the planet is a fundamental parameter that determines our climate. This balance includes energy from the sun, or solar energy, which is an energy source for the planet. Any object that has a temperature emits radiation. The hotter the object, the greater the amount of energy emitted. Energy emitted by terrestrial objects is referred to as terrestrial, infrared, or longwave radiative energy. “

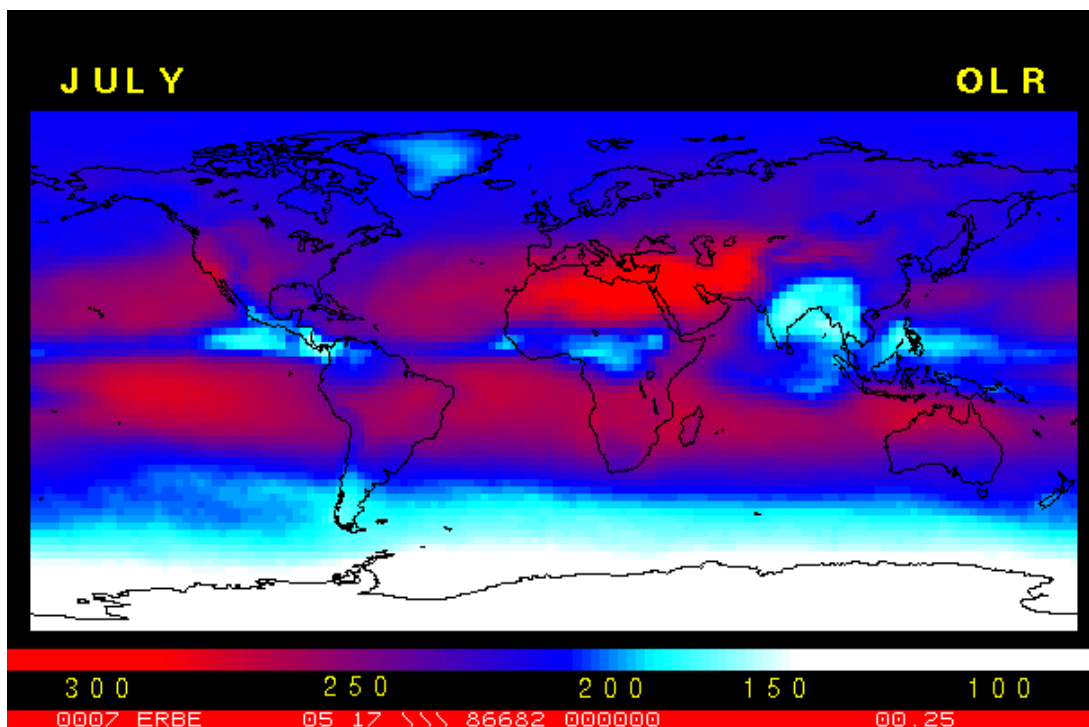
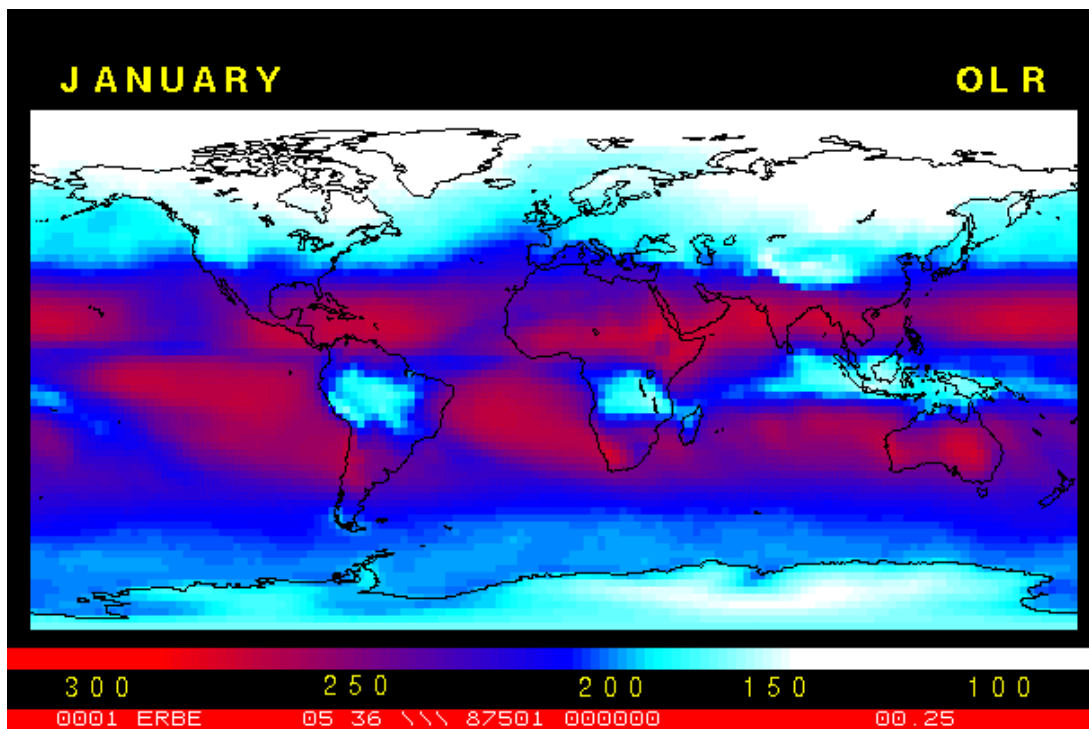
“The determination of the Earth's radiation budget is essential to atmospheric modeling and climate studies. Radiation budget experiments have used satellites to measure the fundamental radiation parameters:

- the amount of solar energy received by the planet,
- the planetary albedo (the portion of incoming solar radiation that is reflected back to space),
- the emitted terrestrial radiation (also referred to as the outgoing longwave radiation -- OLR), and
- the net planetary energy balance (the difference between the absorbed solar energy and the OLR). “

“The planetary averaged [*albedo*](#) is a key climate variable as it, combined with the [*solar constant*](#) determines the radiative energy input to the planet. The global annual averaged albedo is approximately 0.30 (or 30%). The albedo varies quite markedly with geographic region and time of year. Oceans have a low albedo, while snow has a high albedo. While the Northern Hemisphere has more land the Southern Hemisphere, the annual average albedo of the two hemispheres is nearly the same, demonstrating the important influence of clouds in determining the albedo. Notice the high albedo off the west coast of South America. This is a region of persistent low-level clouds – stratus clouds. Can you find other regions of oceanic stratus? “

“Notice the strong dependence of albedo on season; the annual cycle of the albedo follows the annual cycle of the position of the sun. Also notice that cloud free ocean regions have low albedos while deserts generally have high albedos. In the tropical regions the albedo variation is influenced primarily by weather disturbances and their associated cloud distributions. In the Polar Regions, seasonal variations in albedo are due to the distribution of major ice sheets and the decreasing mean solar elevation angle with latitude. Can you explain why Greenland has a very high albedo compared to its surroundings?”

2) Identify the regions with smallest and largest outgoing longwave radiation (OLR) during summer and winter. Briefly discuss the factors contributing to the formation of OLR in these regions.



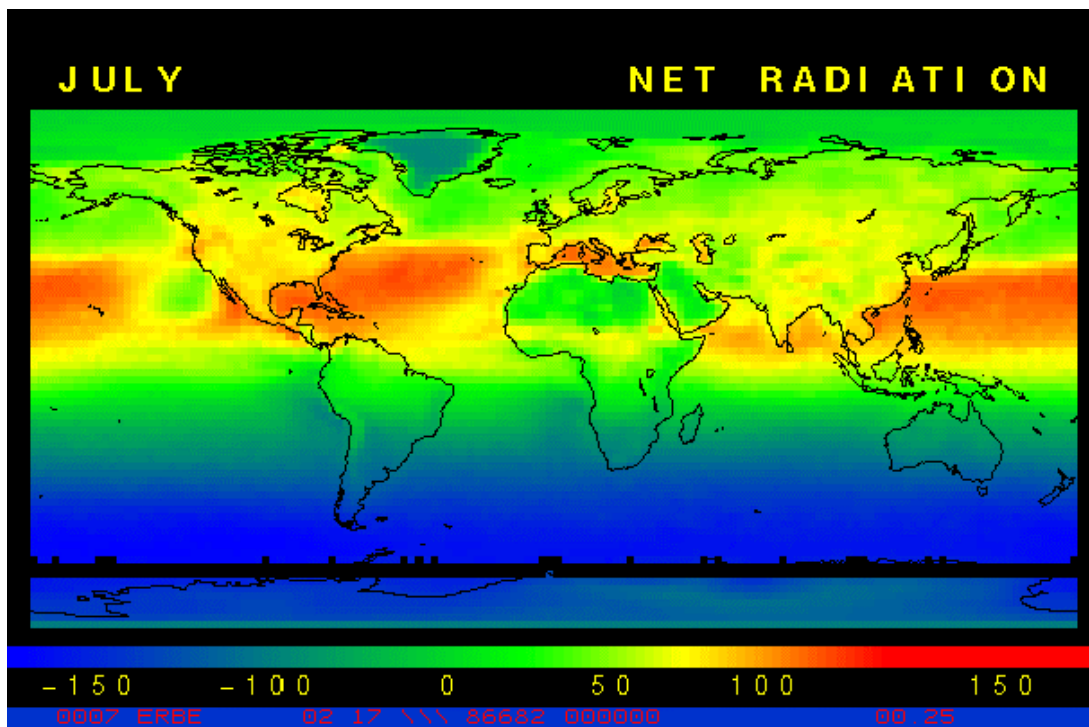
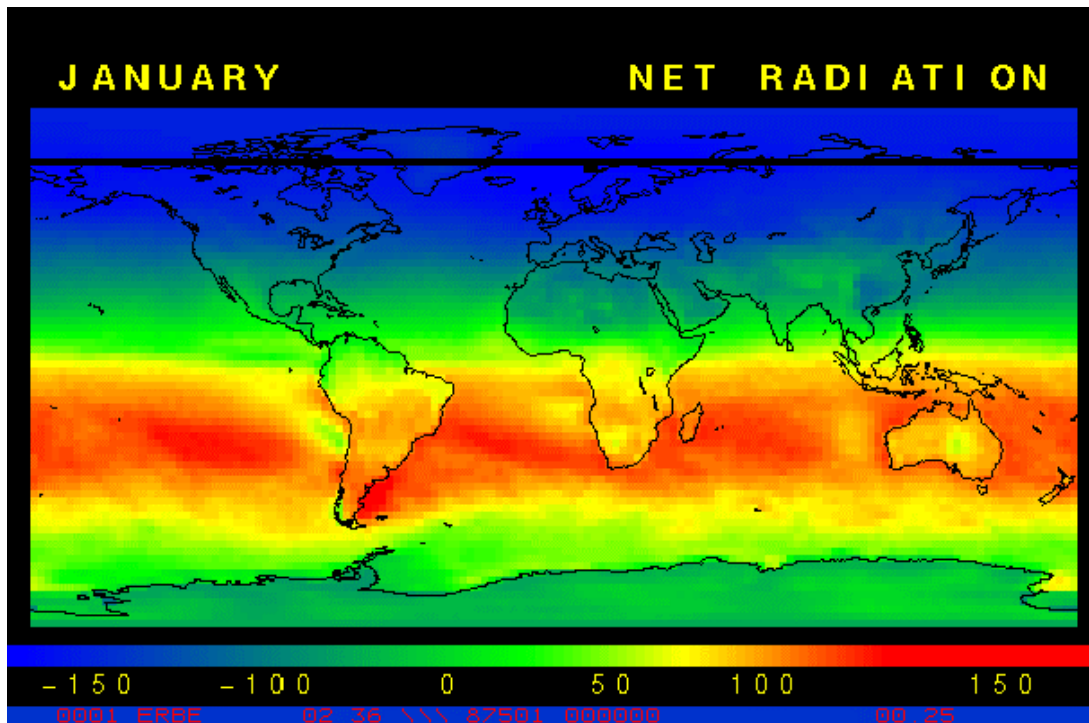
Outgoing Longwave Radiation (OLR)

“The outgoing longwave radiation (or the OLR) is the amount of energy emitted to space by Earth. Low values usually indicate cold temperatures while high values are warm areas of the globe.

The minimum in OLR, or the longwave-emitted flux near the equator is due to the high cloud tops associated with the inter-tropical convergence zone (ITCZ), a region of persistent thunderstorms. This minimum migrates about the equator as seen in the monthly mean maps, and is also seen as a maximum in albedo. Notice how it is difficult to observe the oceanic stratus regions we observed in the albedo maps. This is because the temperature of the clouds is similar to the surrounding oceans, making it difficult to observe.

Observe how the major deserts have their largest OLR during their summer. This results from the annual temperature cycle -- as the desert surface heats up it emits more longwave radiation. Note also the large emission in the vicinity of the oceanic subtropical highs (30N and 30S).”

Compare and discuss the seasonal variation of the net radiation budget in the northern and southern hemispheres.



Net Radiation Budget

“The difference between the absorbed solar energy and the emitted OLR of the planet is referred to as the net radiation budget. The annual variation in net radiative energy follows that of the solar declination due to the annual variation of the incoming solar energy being greater than the annual variation of the albedo.

In general, the absorbed solar radiation exceeds the outgoing longwave radiation in the tropical and subtropical regions, resulting in a net radiative heating of the planet, while in the middle to polar latitudes there is a net cooling. This equator-to-pole difference, or gradient, in radiative heating is the primary mechanism that drives the atmospheric and oceanic circulations. On an annual and long-term basis in which no energy storage and no change in the global mean temperature occurs, this radiative imbalance between the tropics and polar regions must be balanced by meridional heat transport by the atmosphere and oceans.

The measured outgoing longwave radiation and albedo also indicate regional forcing mechanisms. For example, in the tropics east-west variations can be as large as the north-south averages and are associated with east-west circulations. Tropical regions, in general, display a net radiative heating, the Sahara is often experiencing a net radiatively cooling. This is due to the high surface albedo, the warm surface temperatures and the dry and cloud free atmosphere. The radiative cooling is maintained by subsidence warming, which also has a drying effect and therefore helps maintain the desert. “

“The albedo, OLR and net radiation are closely related to surface type and the weather regime. For example, look at the Sahara Desert and the Amazon basin in the summer and winter. The incoming solar radiation is a function of latitude and time of year. The desert is approximate 20 degrees north latitude while the Amazon basin is approximately 20 degrees south of the equator. So the incoming solar radiation in the Amazon in January (Southern Hemisphere Summer) is nearly the same as the incoming solar radiation over the Sahara in July (Northern Hemisphere Summer). The two regions also have very high albedos during their respective summers -- but for two different reasons. The high albedos of the Amazon are the result of highly reflecting deep-convective cloud systems. Over the desert, there are few clouds, but the surface, which is mostly dry soil, is highly reflective. The OLR is very different for these two regions. The amount of terrestrial radiation is a function of temperature, the tops of the convective clouds are very cold, and so the outgoing energy is small. In contrast the desert surface is very warm, and so the OLR is large. What is the difference in the net radiation for these two regions?

Notice also that in the middle and high latitudes of the southern hemisphere, the radiation budget is zonally symmetric -- lines of constant albedo (or OLR) are parallel to the lines of constant latitude. This is not the case in the middle and high latitudes of the northern hemisphere, where contrasts between land and ocean are obvious. It is also interesting to contrast the summer and winter season in the northern middle latitudes. During the summer the OLR is greater over land than the oceans, because the temperatures are warmer, while the albedo is greater over the oceanic regions where there are more clouds. In the net radiation balance, the land surfaces receive more radiation than the oceans. The opposite occurs in the winter -- the oceans gain more radiative energy than the land regions.”

Cloud radiative forcing

“The solar and terrestrial properties of clouds have offsetting effects in terms of the energy balance of the planet. In the longwave, clouds generally reduce the radiation emission to space and thus result in a heating of the planet. While in the solar (or shortwave), clouds reduce the absorbed solar radiation, due to a generally higher albedo than the underlying surface, and thus result in a cooling of the planet.

The latest results from ERBE indicate that in the global mean, clouds reduce the radiative heating of the planet. This cooling is a function of season and ranges from approximately -13 to -21 Wm^{-2} . While these values may seem small, they should be compared with the 4 Wm^{-2} heating predicted by a doubling of atmospheric concentration of carbon dioxide.

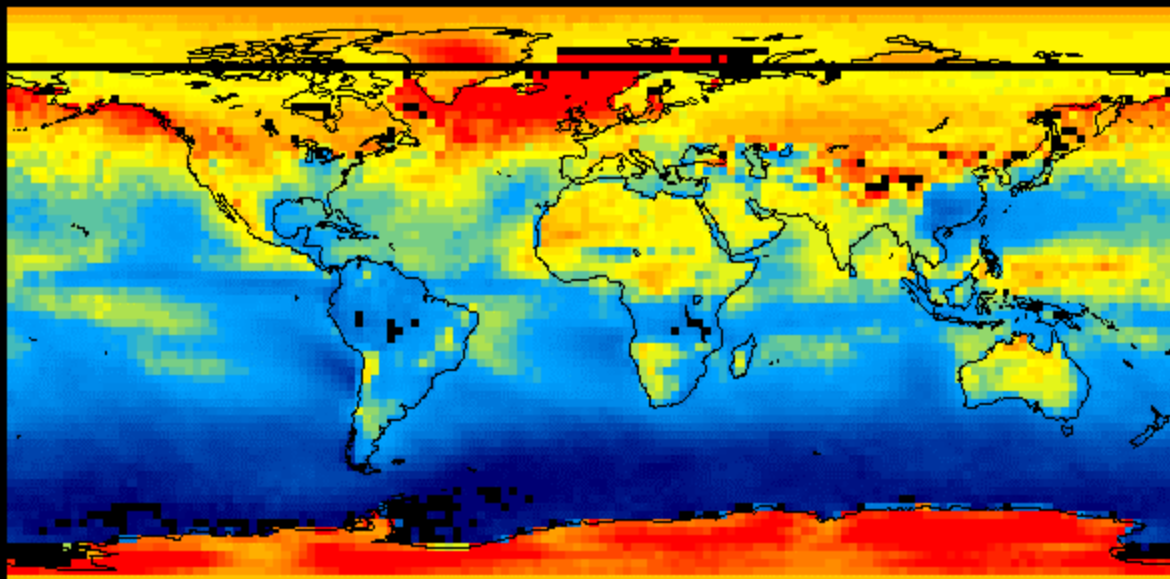
In terms of hemispheric averages, the longwave and shortwave cloud forcing tend to balance each other in the winter hemisphere. In the summer hemisphere, the negative shortwave cloud forcing dominates the positive longwave cloud forcing, and the clouds result in a cooling.

View the maps of cloud forcing given below to answer the following questions:

1. Does the presence of low level clouds over oceans heat or cool the planet?
2. What about the convective clouds over the oceans?
3. Do deserts have a large or small cloud radiative forcing? “

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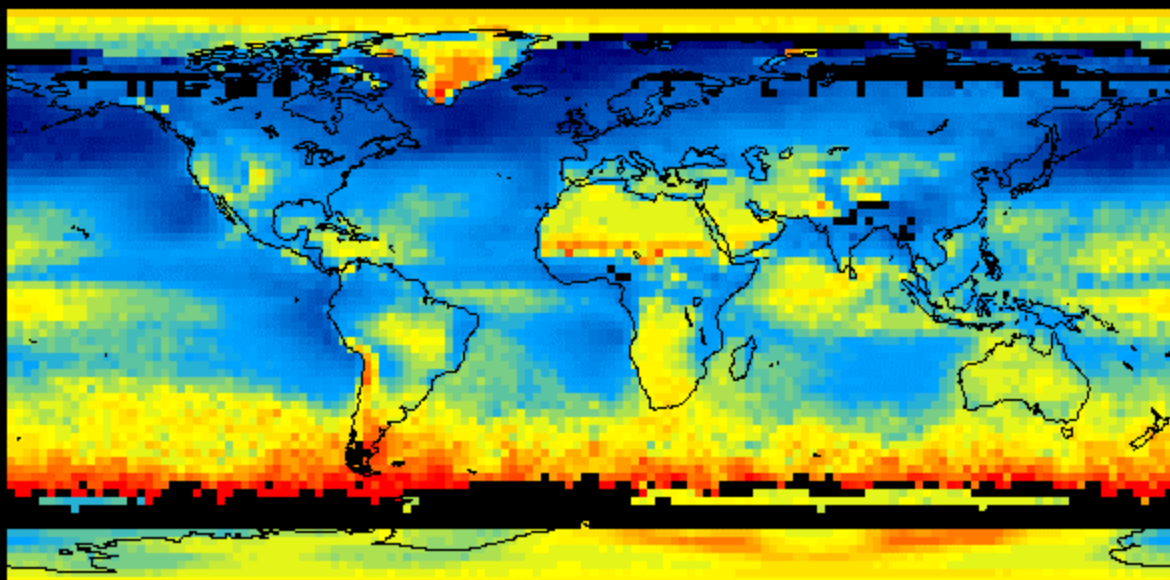
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